Effects of Freshwater Contaminants on Marine Survival in Atlantic Salmon

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There is increasing concern about the continuing decline of wild stocks of Atlantic salmon, *Salmo salar*, throughout the North Atlantic and the impact on commercial and recreational fisheries (Cairns 2001). Recent research has demonstrated that freshwater and marine environments cannot be considered in isolation and that conditions within the freshwater zone experienced by Atlantic salmon may be critical to their subsequent survival in the sea. In particular, exposure of juvenile salmon to a range of sub-lethal concentrations of freshwater contaminants, such as pesticides and endocrine-disrupting chemicals (EDCs), may operate to reduce survival in fish once they have migrated to sea (Madsen et al. 1997).

Freshwater contaminants may act in a number of ways to reduce marine survival. Pesticides such as atrazine may interfere with the parr-smolt transformation (PST), and reduce the ability of the fish to physiologically adapt to saline conditions (Hoar 1988). Atrazine is a widely used pre-emergent herbicide often applied to corn crops, and has high run-off in the first rain after field application (Solomon et al. 1996). Laboratory studies have indicated that smolts exposed in fresh water to environmental levels of atrazine have lower gill $Na^{+}K^{+}$ATPase activity and plasma ion concentrations. Subsequent exposure to seawater resulted in poor hypo-osmoregulatory performance and mortality (Fig. 1). Moreover, modification of the physiological processes involved during smoltification by atrazine may also delay or inhibit smolt migration (Moore et al. in press).

An extensive study has demonstrated a significant relationship between historical applications of an insecticide containing 4-nonylphenol (4-NP), a known EDC, and catch data for Atlantic salmon populations (Fairchild et al. 1999). This study suggested declines in catch were related to exposure during PST. To evaluate this, juvenile salmon were exposed to water-borne 4-NP (5 µg/L) or estrogen (100 ng/L) during the later stages of PST and their subsequent growth and survival followed for 5 months. Caged salmon smolts were also exposed in natural estuarine waters and seawater growth and survival monitored for 3 months. Relative to reference groups, there was a greater proportion of salmon exhibiting poor seawater growth in exposed groups from both laboratory and field experiments (Fig. 2). The response in all cases was bimodal, with growth effects occurring soon after treatments (Brown et al. 2001). Poor growth measured close to PST has been linked to reduced survival and fewer returns of adult salmon to their native streams (Beckman et al. 1999; Friedland et al. 1993). If the effects exerted by 4-NP are due to its estrogenic potential, then steroidogenic activity stemming from other sources (e.g. domestic sewage, agricultural, industrial) (Blackburn et al. 1999; Hewitt and Servos 2001; Sheahan et al. 2002) might negatively influence salmon populations.

The Inner Bay of Fundy (iBoF) Atlantic salmon on the east coast of Canada are distinct genetically from other North American and European populations (mitochondrial DNA analysis), and make a good case study. iBoF Atlantic salmon usually enter rivers in the fall of the year, a high proportion return to spawn after one winter at sea, and survival between consecutive spawnings is high. These salmon are not generally known to migrate to the North Atlantic Ocean (DFO 1998). Recent

Fig. 1. Effects of a 7-day exposure to the herbicide atrazine on seawater adaptability and survival (24 h) of Atlantic salmon smolts.

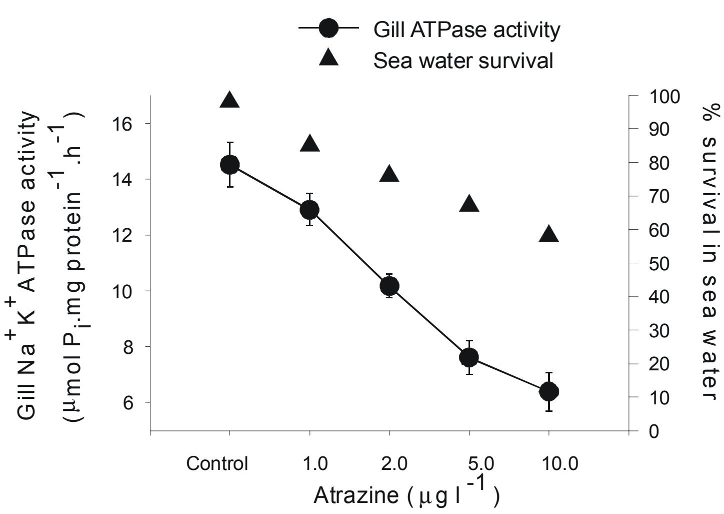

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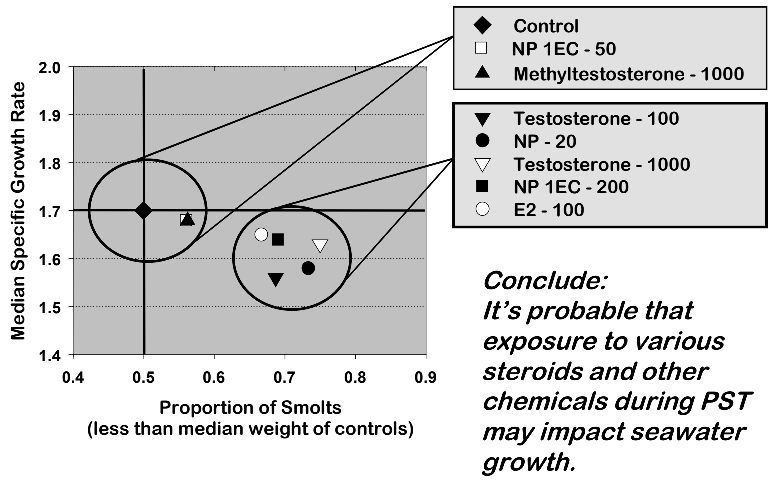
Fig. 2. Specific growth and weight of Atlantic salmon smolts two months after exposure to endocrine disrupting substances, and subsequent grow-out in seawater, St. Andrews Biological Station, 2001. (Legend: E2 = estradiol, NP = nonylphenol, NP1EC = nonylphenoxyacetic acid; units in legend are in µg/L for NP compounds and ng/L for hormones).



performance of iBoF Atlantic salmon populations has been poor. Stocks have been in decline since 1986, and conservation requirements have not been met since 1989. The rivers have been closed to fishing since 1990 (DFO 1998). The iBoF Atlantic salmon were designated as 'endangered' in 2001 (COSEWIC 2001).

Two rivers in the iBoF, the Big Salmon River and the Stewiacke River, account for more than half of the current production, and were historically the largest salmon producers (DFO 1998). The Big Salmon River population had the most pronounced reduction in population of any river in eastern Canada that we evaluated after nonylphenol exposure between 1977 and 1983 (1% of the expected return based on five-year mean in 1980) (Fairchild et al. 1999). This was a singular event in the recorded returns for this river.

In the environment, atrazine is derived primarily from intensive agriculture, and nonylphenol family compounds from sewage treatment plants (STP) and industrial effluents such as textile mills. Monitoring of salmon rivers and estuaries in the iBoF catchment has measured atrazine near agricultural fields (Lakshminarayana et al. 1992; O'Neill and Doull 1992) and nonylphenols in STP effluents (Bennie et al. 1998; Bennie 1999) in the low µg/L range. The concentration range of these measurements is similar to the range described above in experiments that had a negative effect on the growth and survival of smolts. In addition, laboratory studies have indicated that a combination of low environmental levels of atrazine and 4-NP may have a synergistic effect on smoltification, again reducing survival of smolts in seawater (Moore et al. in press).

The concern is that the iBoF salmon smolts may be exposed to atrazine while in streams, and then to nonylphenols in the lower river or estuary; that is, two or more pulses of exposure, a few days apart. This is a very similar pattern to that used in some of the experiments above, and matches the timing pattern of historical forestry spraying of nonylphenol very well. Based on the evidence presented above, it is conceivable that the exposure of the smolts to both atrazine and nonylphenol during downstream migration may subsequently affect growth and mortality of the smolts once they enter the iBoF.

Further work is continuing throughout the geographic range of the Atlantic salmon to determine the role of exposure to mixtures of contaminants on marine survival of salmon and model impacts of contaminants on populations.

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